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U. S. DEPARTMENT OF AGRICULTURE.

FARMERS' BULLETIN 410.

POTATO CULLS AS A SOURCE OF INDUSTRIAL ALCOHOL;

WITH A GENERAL DISCUSSION OF THE AVAILABILITY OF OTHER WASTES.

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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Bureau of Chemistry,
Washington, D. C., May 23, 1910.

Sir: I have the honor to submit to you for approval a report which is intended to reply to the numerous requests for practical information both as regards the apparatus and the methods employed in the manufacture of denatured alcohol from farm waste materials. The description of methods and apparatus for the utilization of waste potatoes or culls is given in detail and from this may be obtained sufficient data to enable one to handle various other cheap or waste materials. As the information contained herein is of particular interest to agricultural communities, I recommend that it be published as a Farmers' Bulletin.

Respectfully,

H. W. Wiley,
Chief, Bureau of Chemistry.

Hon. James Wilson,
Secretary of Agriculture.

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INTRODUCTION.

PURPOSE OF BULLETIN.

This bulletin has been prepared with two purposes in view: First, to outline the conditions which must be considered before attempting to make denatured alcohol, and, second, to give in detail the practical methods for the manufacture of alcohol from potatoes. A discussion of general conditions is given in order to answer the many inquiries received at the Department as to the availability of various materials and it is hoped that persons interested, by a careful reading of this section, will be able to decide for themselves as to the value of any proposed material and the possibility of successfully making alcohol from it under their respective local conditions.

SOURCE OF ALCOHOL.

Alcohol is a substance produced by the fermentation of sugar. In practice there are two possible sources of sugar for this purpose: First, plants naturally containing sugar ready to be converted into alcohol by simple fermentation, such as sugar cane, sugar beets, sorghum, fruits, etc.; second, materials containing starch which may be changed into sugar by the action of malt or acids and then fermented, such as potatoes, grains, cassava, etc. Alcohol has been and is now being made from sawdust, but as the processes employed are trade secrets this material will not be discussed.

NATURE AND USE OF DENATURED ALCOHOL.

The so-called "denatured alcohol" is prepared by the addition of such ingredients as will make the alcohol unfit for drinking purposes. It is used extensively in the manufacture of varnish, explosives, chemicals, and many other commercial articles. It may also be used, in various household appliances, both for lighting and heating purposes with much more safety than either kerosene or gasoline. Its cost previous to the enactment of laws making it tax-free was such as to prevent its use in engines and motors, consequently very little was done toward their adaptation to its use. It is, however, being suc-

cessfully used in both stationary and traction engines in other countries where it can be had at a moderate price, and under similar conditions of economic manufacture would undoubtedly be so used in this country.

CONDITIONS NECESSARY FOR SUCCESSFUL ALCOHOL PRODUCTION.

One per cent of sugar or starch in a product will produce approximately one-half of 1 per cent of alcohol. It is not practicable to distil a fermented solution containing less than 2 or 3 per cent of alcohol. It is therefore evident that materials containing less than 6 per cent of sugar or starch can not be considered suitable for the profitable manufacture of alcohol. Many of the waste materials of the farm may accordingly be eliminated without further consideration. The next point to be considered, after it is decided that the raw material to be used contains sufficient sugar or starch, is the supply of this material and the cost of its delivery to the distillery. Further, there must be available a good supply of water for the condensing apparatus and cheap fuel for the boilers. All of these considerations must be carefully weighed before any attempt is made to establish a distillery. The detailed discussion which is to follow, regarding the location, equipment, and operation of a potato distillery, is applicable, in a general way, to the handling of other waste materials of the farm, and will be valuable as indicating the conditions under which such materials may be successfully used.

SPECIAL AVAILABILITY OF POTATOES.

The reasons for limiting the detailed discussion of this bulletin to the handling of potatoes are as follows: First, potatoes have been successfully used as a source of cheap alcohol in other countries; second, conditions in this country indicate that large quantities of potato culls with the necessary starch content are available for this purpose at a price which would permit of the profitable manufacture of alcohol therefrom; third, the experimental work of the Department distillery has shown how potatoes can be economically handled and practical instructions in the methods of manufacture can now be given; fourth, this work has been done in a small distillery such as would be suitable for large farms or communities of farmers working in cooperation. These data will, in our opinion, enable the farmer to convert frosted or inferior grades of potatoes into a source of revenue, as it has been shown by the experiments that these may be made into alcohol at a fair profit. The apparatus necessary is illustrated and the methods of procedure are given in full. All technical terms have been omitted and the subject discussed from a practical rather than a theoretical point of view.

FUNDAMENTAL CONSIDERATIONS IN ESTABLISHING A POTATO DISTILLERY.

LOCATION.

The first consideration is that the distillery be centrally located in a potato-raising country; second, that there are railroad facilities for the delivery of raw materials and fuel and the marketing of the finished product at a minimum expense. An abundant supply of cold soft water is of almost equal importance. It is desirable that the plant be near a creek or stream from which the water may be obtained and into which it may be drained after serving its purpose in the distillery. The character of the water should also be considered, and, if possible, it should be such that it will not deposit a scale on the boiler and condenser tubes; this difficulty can be overcome, however, by treating the water with one of the various compounds on the market for relieving such conditions. The possibility of handling and housing cattle to be fattened on distillery waste should also be considered.

MACHINERY AND EQUIPMENT.

The machinery should be such as will permit of economy in operation together with a high degree of efficiency. As a distillery in most cases would not be operated during the entire year, which invariably means a change in the working force for each season's operation, and as skilled labor is not always available, the machinery should be as simple as is practicable. It must be remembered, however, that with more costly machinery and apparatus better results can be obtained. The equipment should be so installed that its operating cost will be reduced to a minimum, and so arranged as to allow any part to be thrown out of motion when not in actual use. It should be as compact as possible without being crowded, and permit the proper handling of the material with the least amount of labor. The construction should be such that the exact result of each day's operation may be easily ascertained.

Advantage should be taken of the laws of gravity to save pumping whenever possible. This can be done by arranging the apparatus so that each operation will be made on a higher level than the succeeding one; thus by elevating the raw material to a height suitable for the first operation, it will flow from one apparatus to another by its own weight. All machinery requiring steam should be placed close to the boiler so as to avoid condensation caused by long pipe connections. Exhaust steam from the engine and pumps should be used in the distilling apparatus, and the hot water from the condensers should be utilized as feed water for the boiler.

With the exception of the boiler, each piece of apparatus should have a capacity equal to the exact amount of work it is expected to perform, and should be properly proportioned to the rest of the equipment. As the proper working of each piece depends upon the efficiency of the boiler, it is best to have this extremely important part of the equipment of a slightly larger capacity than is actually required, so that it can supply any piece of apparatus with more than its usual amount of steam in case this should be found necessary. The machinery selected, therefore, should be simple, practical, efficient, and economical.

The information as to sizes and proportion of equipment can be obtained from manufacturers of distilling apparatus by informing them as to the kind and amount of material to be used and the conditions under which the work is to be done.

CONTROL OF OPERATION.

The economy of operation will depend entirely upon the control exercised over each piece of apparatus and each person in the plant. The capacity of each piece should be known and the results of its work observed each day, so as to determine whether it has been overtaxed or has failed to do its full share of work. The entire operation should be kept under such control that in case of error it may be traced and attributed either to the negligence of some person or to the inefficiency of some piece of apparatus. A schedule of each day's operation should be kept, so as to know whether or not the largest possible yields are being obtained from the amount of material handled.

It is advisable to operate a distillery only during the colder months; for instance, from early autumn until late in the spring. During this time the temperature of the cooling water will be considerably lower than in the warmer months, the amount required correspondingly less, and the time required for cooling decidedly shortened. This means a shorter working day, and consequently less wear on the machinery and a considerable saving of fuel. It is essential that a distillery be operated daily, and not intermittently, as each day's work depends in a greater or less degree both upon that of the preceding and the following day.

There is still another very important point, namely, cleanliness, and upon this the yield of alcohol will in a great measure depend. Material which is nutritious for yeast (the alcohol ferment) also nourishes other organisms, which thrive upon it equally as well, but do not produce alcohol. The presence of these organisms is due to the souring of small bits of mash which have not been washed out of the apparatus. This state of affairs can easily be avoided by steaming or by

allowing water to flow through the apparatus at the close of each day's work. Cleanliness is especially necessary in the case of the yeast and fermenting tubs, where the intrusion of these organisms will cause serious trouble. The walls of the distillery should be kept free from mold by an occasional coat of whitewash. The floors should be flooded daily, and the sewer connections must be adequate to remove the water and other wastes from the premises.

ESTIMATED COSTS OF A POTATO DISTILLERY.

COST OF PLANT.

The following data give some idea of the cost of installing and operating a plant of moderate capacity and the approximate value of its products. It will be supposed that the plant under consideration has a capacity for handling 8,000 pounds of potatoes (equal to 1,000 gallons of mash) in one working-day of ten hours, and that the building is one story high, requiring a ground space of about 1,000 square feet. The walls may be constructed of any available material. Wood sheathing covered with corrugated galvanized iron will be economical and serviceable. In many cases farm buildings such as barns, etc., could be used. Such a building will not cost more than $1,500. The total cost of machinery and equipment, not including the motive power, will be about $9,000. One 75-horsepower boiler and a 25-horsepower engine will be required, at an additional cost of about $1,500. The cost of erection need not be considered, as a plant of this size would be furnished by the manufacturers in such shape that the purchaser could erect it himself. This would make the total investment amount approximately to $12,000.

Of necessity all such estimates of the cost of equipment, operation, and the value of the output involve some hypothetical factors and will vary under different economic conditions. The data given, however, are based on actual experience and may be considered as a rational working basis on which any individual may form an opinion as to the probability of manufacturing alcohol successfully, from a financial point of view, under his own economic conditions. If any one of the factors, such as cost of labor or of raw materials, varies under local conditions from the values here used, due allowance must be made in working out the individual problem, but the factors to be considered and the principles involved remain the same.

COST OF OPERATION.

The expense of a day's operation will include the cost of potatoes, barley, fuel, and labor. From inquiries made by the Department, cull potatoes can be delivered at a distillery in some potato-growing districts at 25 cents per hundred pounds. At this rate the raw

material for a day's run of 8,000 pounds would cost $20. There will be needed to convert the starch in the potatoes into sugar the amount of green malt yielded by 120 pounds of barley, which at 70 cents per bushel will cost $1.75. The cost of fuel will vary with the skill of the fireman, but with a proper utilization of the fuel (soft coal) 1 ton at $4 should be sufficient for each day's operation. The services of three men will be required, namely, one competent foreman and two laborers. This will make a total of about $33 for daily operating expense.

VALUE OF OUTPUT.

The products will consist of alcohol and "slop." As shown elsewhere in this bulletin, about 1.3 gallons of denatured alcohol, 180° proof,[a] can be obtained from 100 pounds of potatoes. The total amount of alcohol produced per day will therefore be about 104 gallons of 90 per cent alcohol, or about 187 gallons of 100° proof, or 50 per cent alcohol, on which the internal-revenue regulations are based, which at about 40 cents per gallon will be worth $41.60. There will be about 1,000 gallons of slop. As shown in the chapter on slop feeding, 20 gallons per day per head is sufficient for fattening oxen, so that the slop from one day's operation will form the major portion of rations for 50 head of cattle.

Such a distillery as this is somewhat larger than is contemplated for the so-called industrial plant, being better suited for a community or a cooperative plant. A plant with a capacity of 100 proof gallons (50 per cent alcohol) per day or less, designated by the Government as an industrial distillery, for which special regulations and privileges are granted, will be better suited for individual farmers. The cost of the smaller plant will be less, but the operating expense will not be decreased in proportion to the size, which makes the larger plant more economical and therefore more likely to succeed. The cost given may be used as a basis for estimating that of a plant of any size, but the exact figures can be obtained from the manufacturers of distillery machinery.

GOVERNMENT REGULATIONS.

When the erection of a distillery is contemplated it is necessary that notice to that effect be given to the internal-revenue authorities and that the laws and regulations relating to such a business be complied with. The regulations may at first seem complicated, but they are found necessary by the Government in order to prevent fraud, and can easily be followed when one is familiar with them. They consist chiefly of monthly reports to be furnished to the Bureau of

[a] In the United States "proof spirit," or 100° proof alcohol, is an alcoholic liquor containing one-half its volume of absolute alcohol at 60° F. A product of 180° proof is said, therefore, to be "above proof," and contains 90 per cent of alcohol by volume.

Internal Revenue showing the amount of raw material used, the amount of alcohol manufactured, and the disposition made of same. Agricultural distilleries manufacturing less than 100 proof gallons per day are exempt from many of the regulations applying to plants of larger capacity. All the necessary information can be obtained by applying to the collector of internal revenue of the district in which the distillery is to be located. Regulation No. 30, Revised, relating to denatured alcohol, can be had by applying to the Bureau of Internal Revenue, Washington, D. C.

DETAILS OF OPERATING A POTATO DISTILLERY.

In manufacturing alcohol from potatoes they are first washed and then cooked so that the starch present can be readily converted into sugar by the action of malt. The sugar so formed is fermented by the addition of yeast and the alcohol contained in the fermented liquid is separated from it by the process of distillation. The detailed operation is as follows:

PREPARATION OF THE MASH.

The potatoes, after being weighed in the weighing bin, are run down a slatted chute into the cooker manhole as shown in figure 1. The slats on the underside of the chute are spaced so as to allow only the sticks and dirt to fall through. When the cooker is filled, the potatoes are washed by playing a stream of water upon them through the manhole, the dirt and water being drained off by means of the escape valve. After the potatoes are thoroughly cleaned the manhole cover is put on and bolted, and steam is admitted into the top of the cooker by the valve *C*, the escape valve being left open so as to allow the condensed water to discharge at *B*. After the potatoes have been well warmed and steam begins to come out of the escape valve, the latter is closed. The steam is then shut off at the top of the cooker and admitted at the bottom through a series of inlets from the steam pipe *D*. The blow-off valve *E*, at the top of the cooker, is now partially opened. By allowing a small amount of steam to escape from this valve the potatoes are shaken up and thoroughly disintegrated. The steam pressure in the cooker is now allowed to rise gradually to about 50 or 60 pounds, when the blow-off valve should be closed. The entire time required for warming the potatoes and reaching the maximum pressure should be about one hour. The stirrer *G* is then started, and the maximum pressure held for about ten minutes to insure a thorough cooking of the starch in the potatoes, after which the steam is shut off.

The blow-off valve is then opened wide and the temperature inside the cooker allowed to fall to 212° F. The temperature of the cooked potatoes is further reduced by means of the vacuum pump to from 140° to 145° F., at which point the malt (see p. 19) necessary to change the starch into sugar is added. About 2 pounds of malt are used for each 100 pounds of potatoes mashed, the exact amount depending upon the quantity of starch in the potatoes and the quality of the malt. This proportion will apply either in the use of green or dried malt, as the diastatic power (i. e., the ability to change starch into sugar) of each is about the same.

Green malt is crushed between rolls, while dried malt is ground in a mill before using. About fifteen minutes before the mash in the cooker is ready for malting, the malt, already crushed or ground, as the case may be, is mixed with water in the proportion of 1 gallon of water to 2.5 pounds of dried malt, or three-fourths gallon of water

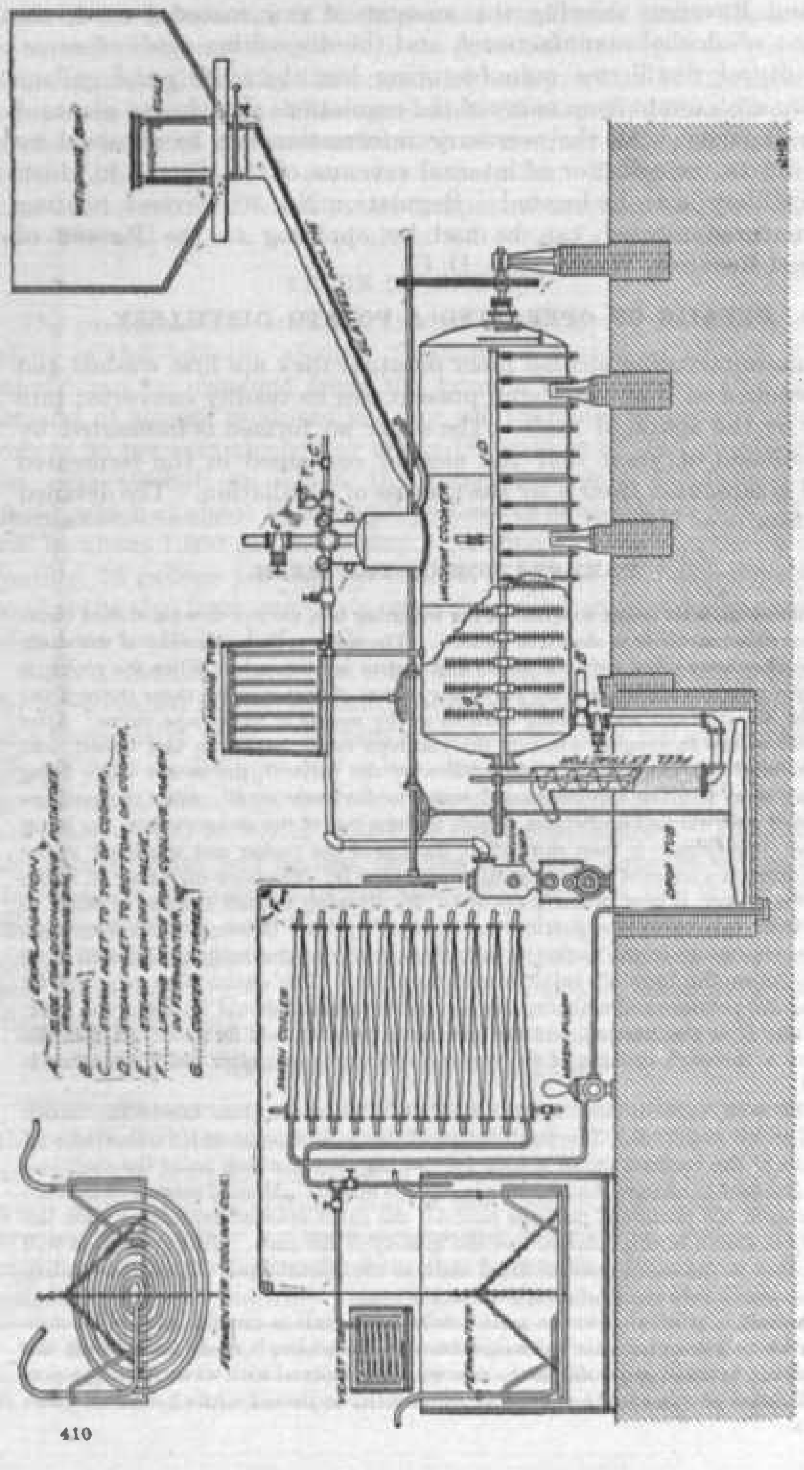

FIG. 1.—Mashing and fermenting apparatus for potato distillery.

to the same amount of green malt. It is prepared in a tub situated above the cooker and allowed to drop into the latter when the temperature of the cooked mash has been reduced to about 140° or 145° F. The diastase in the malt will dissolve the cooked starch and convert it into a fermentable sugar. This conversion will be complete in about fifteen or twenty minutes, during which time the mash should be constantly stirred. In order to know whether or not the conversion is complete, a few drops of iodin solution [a] are added to a little mash which has been filtered through a cheese-cloth bag and placed upon a porcelain dish or some other white surface. If the mixture turns blue it indicates the presence of unconverted starch and it is then necessary either to increase the amount of malt or the time of conversion. Further tests should be made until the blue color is no longer obtained, which indicates that the change of starch into sugar has been completed.

The mash is now ready to be cooled and sent to the fermenter, but to insure easy handling through the pumps and distilling apparatus it is necessary to remove the skins and the fibrous or woody parts of the potato which have not been broken up during the cooking process. The entire mash on leaving the cooker, therefore, is run through the potato-peel extractor, which is placed in the drop tub. This consists of an upright perforated copper cylinder on the inside of which is a revolving spiral, which carries the hulls and lumps to the top of the cylinder, where they are discharged through a spout, the liquid portion flowing through the perforations into the drop tub. The cleaned mash is now pumped through the mash cooler, where it is reduced to the so-called pitching [b] temperature, by circulating a constant stream of cold water through a pipe surrounding the pipe through which the mash passes. The pitching temperature most favorable for fermentation varies between 60° and 70° F., depending upon the weather conditions and the volume of the mash. It should be such that the mash will show signs of active fermentation in a few hours after being run into the fermenter. At the same time that the mash is run into the fermenter the yeast mash (about 3 per cent by volume of the main mash) is also added. It is prepared (see chapter on yeast, p. 24) in a tub placed above the level of the fermenter, so that it may be easily discharged into it.

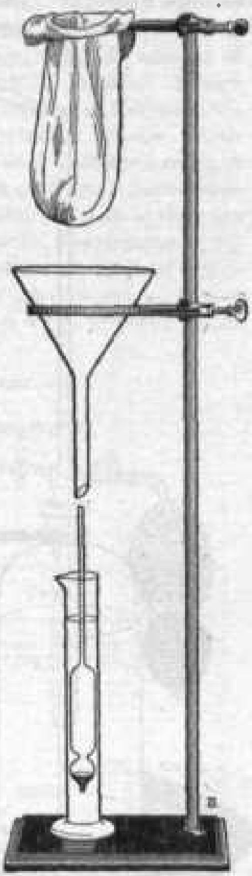

FIG. 2.—Apparatus for determining the specific gravity of a mash.

FERMENTING THE MASH.

After the yeast and mash are in the fermenter the process of fermentation will begin and the sugar in solution be broken down into alcohol and carbon dioxid gas. The gas will pass off into the air and the alcohol remain in the solution. At this point it is important to know the gravity and acidity of the *set mash*, as it is now called. The specific gravity indicates the amount of sugar or fermentable material contained in the mash and is ascertained as follows: The mash is thoroughly stirred and a small portion filtered through a cheese-cloth bag into a suitable cylinder, as shown in figure 2. A Balling saccharimeter is placed in the

[a] The solution of iodin is prepared by adding 2.5 drams of potassium iodid and 75 grains of iodin (which can be bought at any drug store) to 1 quart of water and shaking until thoroughly dissolved.

[b] "Pitching the mash" means setting it with the yeast to ferment.

filtered liquid and the reading indicated on it at the liquor level will be the gravity of the mash. This reading should be from 16° to 18°, which means that the mash contains from 16 to 18 per cent of solids, most of which is sugar.

The acidity of the *set mash*, or the amount of acid present, is due to the acidity acquired by the *yeast mash* and the natural acidity of the potatoes. It is determined by neutralizing a small portion of the mash with a normal solution of sodium hydroxid[a] and the amount of the latter required will represent the acidity of the mash. This is done by means of the apparatus shown in figure 3. The bottle *A* contains the solution of sodium hydroxid. The burette *B* used for measuring the solution is filled by squeezing the rubber bulb. A small portion of the mash is filtered through a filter paper and 20 cc of the filtered liquid, measured in the pipette *C*, are poured into the beaker *D*. The solution is allowed to drop slowly from the burette into the beaker, the mixture being constantly stirred until the acid contained in the filtered liquid has been neutralized. The neutral point is determined by placing a drop of the mixture upon litmus paper. When it will not turn blue litmus paper red, nor red litmus paper blue, but leaves it unaltered, the mixture will be neutral, and the number of cubic centimeters of the solution of sodium hydroxid used, which can be read directly from the burette, will represent the acidity of the mash.[b]

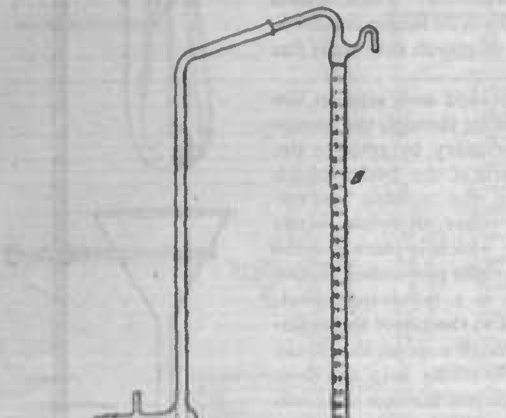

FIG. 3.—Apparatus for determining the acidity of a mash.

After the mash has been set about ten or twelve hours the fermentation will become vigorous and the temperature begin to rise rapidly, but it should not be allowed to go much above 80° F., as quite an amount of alcohol due to evaporation would be lost at a higher temperature. To prevent further rise in temperature, it is necessary to equip the fermenter with a coil through which cold water is circulated. This coil is so arranged that it may be raised or lowered very slowly in the mash by means of a suitable device, the simplest way being by the conversion of the circular motion of a pulley into an up-and-down motion by means of a rope and tackle. The fermentation is allowed to continue at a temperature between 60° to 80° F. for seventy-two hours, except in the case of mashes made the latter part of the week, when it goes on for ninety-six hours, as no distillations may be made on Sunday. At the end of this time the fermentation will be complete, provided the yeast was in a normal condition.

[a] This solution can be bought already prepared of any chemical supply house.
[b] All acidities given in this bulletin were determined on this basis.

DETERMINATION OF THE GRAVITY AND ACIDITY OF THE FERMENTED MASH.

To find out how much of the fermentable material originally contained in the mash has been utilized (i. e., the amount of sugar that has been converted into alcohol), it is necessary to determine the gravity of the fermented mash (as shown in figure 2), which should have gone down to about 1.5 to 2 on the saccharimeter. It is also extremely important that the acidity of the fermented mash be determined and compared with that of the unfermented or set mash. The acidity should remain about the same during the entire fermentation, but in some cases there may be a slight increase. The fermentation can withstand, and, in fact, is protected by, a certain amount of acid, but the presence of an excess will seriously interfere with its progress. A large increase in acidity in the fermenters is generally due to the formation of butyric acid, which is highly objectionable. This acid can be readily detected by its odor, which resembles that of rank butter and is caused by allowing portions of fermented mash to sour in the fermenters, or by not thoroughly cleaning them after each use. Such a condition can be prevented or removed by scrubbing the fermenters, as soon as they are emptied, with a 5 per cent solution of formalin or other powerful disinfectant, or by applying a coat of whitewash to the inside of the fermenters and washing it off before refilling. In order to control the fermentation properly, the gravity and acidity of the mash are determined every twenty-four hours and a record kept, as shown in the following form:

Mashing, fermentation, and distillation record.

Experimental Distillery No. 1. Located at Washington.

Fermenter No. 3. Set January 22. Distilled January 25.

MASHING RECORD.

Materials.

Kinds.	Yeast mash.		Main mash.		Total.		Starch.
	Pounds.	*Gallons.*	*Pounds.*	*Gallons.*	*Pounds.*	*Gallons.*	*Per cent.*
Potatoes	400	50	7,600	950	8,000	1,000	17
Green malt	25		156				

FERMENTATION RECORD.

Yeast mash.				Main mash.			
Date.	°Balling.	Temperature.	Acidity.	Date.	°Balling.	Temperature.	Acidity.
1910.		*°F.*		1910.		*°F.*	
January 20	22	132	0.8	January 22	18.0	67	0.70
21	22	65	2.5	23	10.6	77	.75
22	5	77	2.5	24	3.5	77	.75
				25	1.5	75	.75

DISTILLATION RECORD.

Wine gallons 104   Proof .... 180°   Proof gallons 187

As before stated, the gravity should fall rapidly and the acidity remain about the same or increase slightly. If this is not the case, the mash has either been pitched at a temperature too low for the proper development of the yeast, or acid-forming organisms have become active and are retarding the fermentation. If tempera-

ture conditions have been the cause, the following mash can be pitched a little higher; but if injurious organisms have gained control in the mash, they must be suppressed at once so as to prevent the following mashes from becoming infected also. The amount of alcohol contained in the fermented mash will vary according to the gravity of the set mash, and as alcohol boils at a lower temperature than the other constituents it can be separated by distillation.

DISTILLING THE ALCOHOL.

In figure 4 is shown a distilling apparatus especially adapted for the economic separation of the alcohol from the mash. It is not complicated, as it might appear at first glance, but is decidedly simple and requires little attention after it has been once regulated. The fermented mash is pumped slowly into the distilling apparatus, where it is brought in contact with live steam, which boils it and carries off the alcohol in the form of vapor, which in turn is passed through a condenser, where it is reduced to a liquid. The distilling apparatus consists of two copper columns, *A* and *B*, *A* being used to distil the alcohol from the mash and deliver it in the form of vapor to *B*, where it is redistilled and raised to the desired strength.

The apparatus is operated as follows:

The fermented mash is continually discharged from pump 1 and pipe 2 into the mash heater 3. This heater contains a series of tubes through which the mash is passed and around which the vapors coming from the boiling mash in *A* on their way to *B* are circulated. The heated mash leaves the heater through pipe 4 and reenters the column below the heater where it comes in contact with steam. The lower part of the column is divided by plates into a series of chambers in each of which the mash is boiled and relieved of some of its alcohol. The mash takes a downward course through the drop pipes and across each of the various plates. It will lose all of its alcohol by the time it reaches the bottom chamber of the column, from which it is automatically discharged through valve 5. The shaded lines show its course. A small portion of the vapors in the bottom chamber of column *A* is delivered by pipe 6 to the condenser 7, where it is condensed and tested to ascertain if there is any alcohol being lost in the "slop," as the discharged mash is ordinarily called.

The steam necessary to boil the mash is admitted into the bottom chamber of column *A* through the pipe 8. It boils the mash in this chamber and passes upward through each succeeding chamber, boiling the descending mash and carrying with it the alcoholic vapors. The plates within column *A* are perforated so as to allow the steam to pass through them, but the mash is prevented from falling through the perforations by the steam pressure. The vapors rise to the upper part of column *A* and are conveyed through the pipe 9 into the heater 3, where they are circulated about the tubes containing the mash passing through the heater, and then are carried through the pipe 10 into the bottom of column *B*.

The vapors coming from *A* contain a considerable amount of moisture and other impurities of which they are freed in column *B*, which contains a series of chambers upon each of which is carried about 3 inches of liquid. A constant level is maintained in each chamber by means of the drop pipes. The plates between the chambers are not perforated as in column *A*, but the vapors ascend from one chamber to another through a pipe in the center of the plate and are deflected downward by a hood over the pipe and forced to boil their way through the liquid on each plate. The arrows indicate their course. The vapors boil from chamber to chamber, becoming purer as they ascend until they reach the top chamber of the column, from which they are delivered through the pipe 11 into the cooler 12, where they are partially cooled. From the cooler they pass through pipe 13 into the condenser 14, where they are reduced to a liquid. This cooling and condensing is effected by circulating cold water around the tubes containing the vapor.

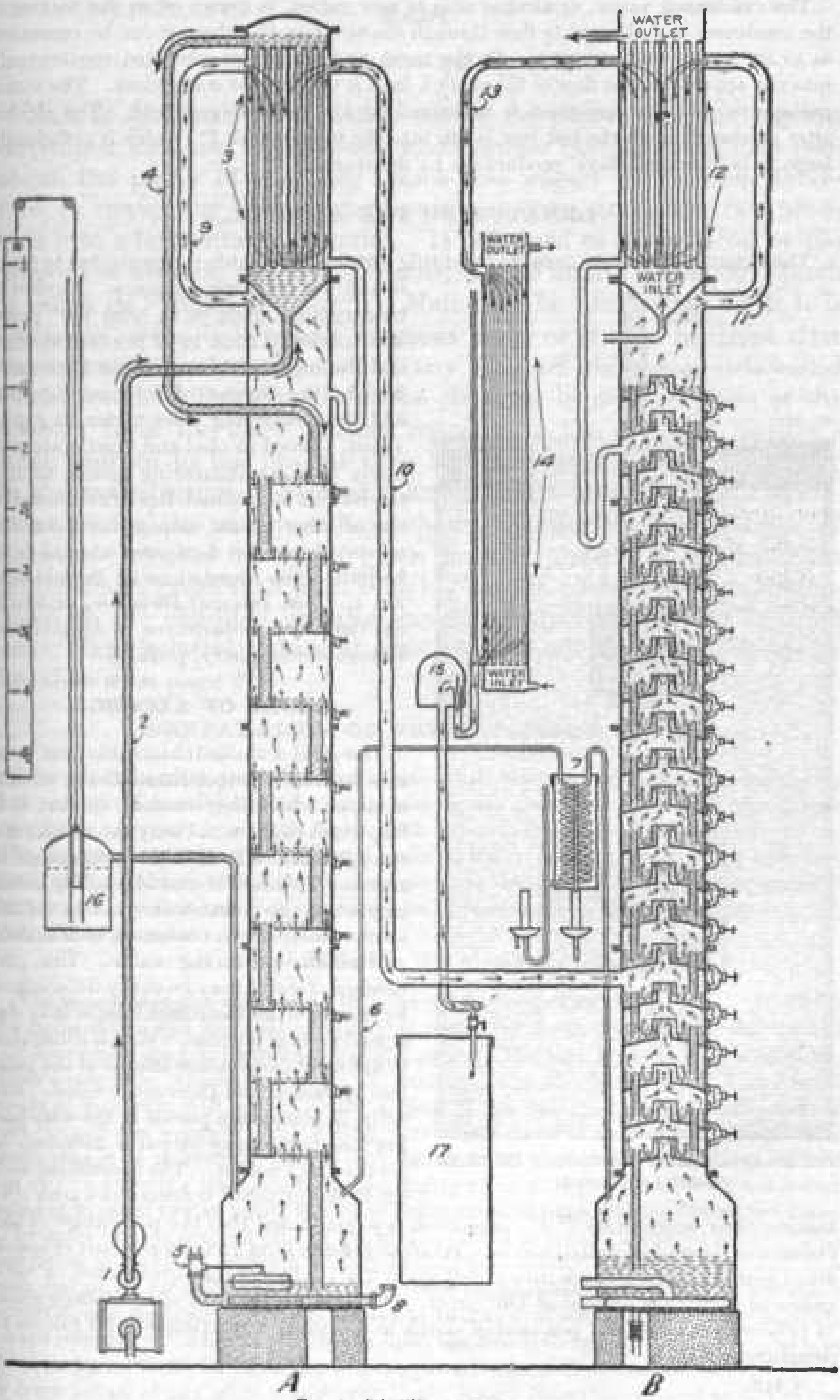

FIG. 4.—Distilling apparatus.

The condensed vapor, or alcohol as it is now called, is drawn off at the bottom of the condenser and allowed to flow through the test box 15, where it can be examined as to its purity and strength. As the mash and steam are admitted continuously into the apparatus, the flow of the alcohol from it will also be continuous. The steam pressure within the apparatus is registered by the pressure gauge 16. The alcohol after passing through the test box is run into the storage tank 17 (which is sufficiently large to hold several days' product) to be denatured.

DENATURING THE ALCOHOL.

The denaturing process consists in adding certain ingredients to the alcohol to make it unfit for drinking purposes. Alcohol to be denatured must be at least 180° proof, which is equivalent to 90 per cent alcohol, and the ingredients used must be authorized by the Bureau of Internal Revenue and the denaturing done under its supervision. Wood alcohol and benzin are generally used as denaturing agents, though the Bureau of Internal Revenue allows the use of other agents, depending upon the use to which the denatured alcohol is to be put. (See Regulations 30, Supplement No. 1, U. S. Internal Revenue, or Bulletin 130, U. S. Department of Agriculture, Bureau of Chemistry, p. 161.)

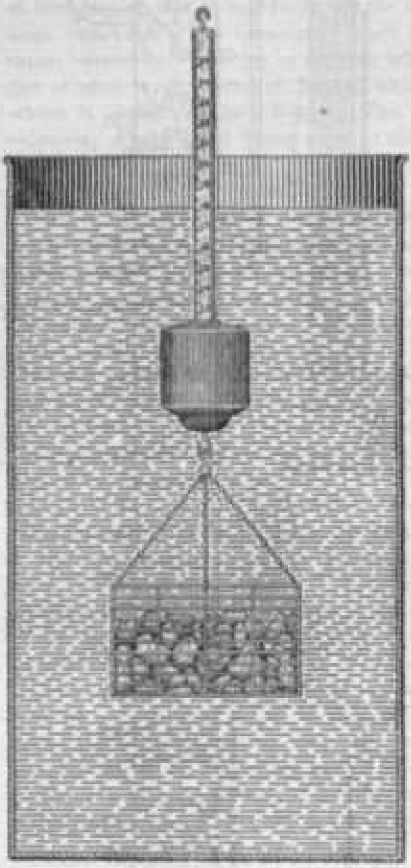

FIG. 5.—Apparatus for determining the starch content of potatoes.

YIELD OF ALCOHOL.

The yield of alcohol obtainable from potatoes is directly proportionate to the amount of starch which they contain, so that it is important to know not only the weight of a consignment, but also the percentage of starch. This is of course absolutely necessary when the potatoes are paid for on the basis of their starch content, which is their real alcohol-producing value. The percentage of starch may be easily determined by means of an instrument especially designed for that purpose, which is illustrated in figure 5. An average sample of the potatoes is washed and thoroughly dried. Exactly 10 pounds are placed in the wire basket (one potato may be cut if necessary to get the exact weight). The instrument with the basket attached is floated in a tank containing clear water at 63.5° F. The stem is so graduated that the percentage of the starch can be read directly from it. Potatoes average from 14 to 20 per cent of starch and 1 pound of starch in practice yields about 0.071 gallon of absolute alcohol, or 0.079 gallon of denatured alcohol at 180° proof. One hundred pounds of an average grade of potatoes containing 17 per cent of starch would yield approximately 1.3 gallons of denatured alcohol.

MALT.

DIASTATIC POWER OF MALT.

Malt is sprouted grain, which during its period of sprouting has developed diastase, a substance which under certain conditions possesses the power of changing starch into sugar. It is used, therefore, in converting the starch of potatoes, corn, and other raw products into a fermentable material. It is judged as to its value by the amount of diastase which it contains, and its ability to convert starch is called its "diastatic power." Malt may be used either while it is sprouting, when it is known as green malt, or it may be dried after the sprouting period and used at any time, in which case it is called "dried malt." Dried malt can be obtained in most sections of the country from the large malting concerns in the shape of distiller's malt, and up to the present time has been used almost exclusively in the manufacture of alcohol. Experiments made by this Department during the past year have shown that for the manufacture of denatured alcohol the use of green malt is preferable. It has been found that a green malt with a high diastatic power can be manufactured on the distillery premises for about one-half the cost of dried malt. The relative values of green malt made from various grains are shown on page 22.

PREPARATION OF GREEN BARLEY MALT.

The principle employed in malting is practically the same for all grains, there being two operations, namely, the soaking or steeping and the sprouting or growing. These operations vary only in a slight degree with different grains according to their nature. The steeping consists of soaking the grain in water until it has absorbed sufficient moisture to enable it to sprout when spread upon the malting floor. A good grade of barley and one that has been harvested for at least three months should be selected for malting purposes.

Steeping the Grain.

The style of steeping tank shown in figure 6 is best suited for this purpose. It should be made of iron and mounted on rollers, so that it can be easily moved to that part of the floor where the grain is to be spread and grown. The tank is partly filled with clear, fresh water from *A*, and the barley allowed to run in slowly. The chaff and weed seeds in the grain will remain on the surface of the water, and can be easily floated out through the overflow *B* by adding water until its level rises to that point. The grain should be thoroughly washed by running water through the tank, to be drained off at *C*. After the grain has been thoroughly cleaned it is covered with water and allowed to stand twelve hours, the water being replaced once or twice during this time. The water is then drained off and the grain allowed to stand for twelve hours. This operation is repeated during the next twenty-four hours. The steeping which has now continued for two days will in most cases be complete; however, it is advisable sometimes to continue it for from twelve to twenty-four hours longer. The duration of the steeping will depend principally upon the size of the grain and the temperature of the water. Corn, for example, will require a longer time to steep than barley, and a large kernel of any grain a correspondingly longer time than a small kernel of the

same kind. It is, therefore, important that grain of a uniform size be selected in order that the steeping may be even.

It is impossible to fix a definite length of time for this operation. However, this is not important, as a slightly insufficient steeping or a little oversteeping will not make any material difference; the former is less dangerous than the latter, because in the case of insufficient steeping the grain may be sprinkled after it has been placed upon the floor, while in the case of oversteeping it is liable to rot. When the grain can be crushed between the thumb and fingers and the inside is not hard and glassy, but has become soft and chalk-like, the steeping is completed. The grain is then ready to be dropped upon the floor through the valve *D* to be sprouted or grown, as it is ordinarily called.

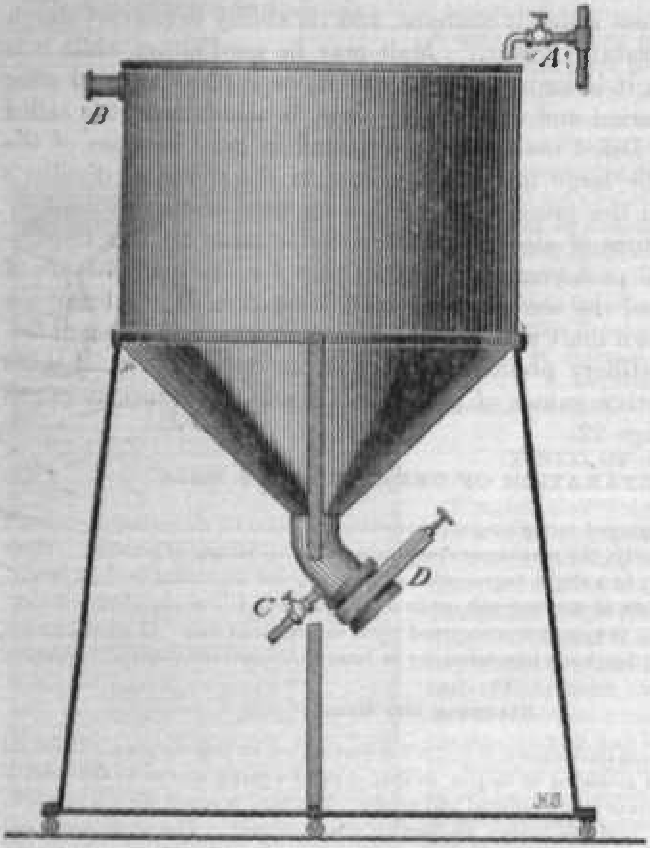

Fig. 6.—Barley steeping tank.

Sprouting the Grain.

The floor on which the grain is grown should be smooth, preferably of cement, with a slight slope so as to allow the water used in sprinkling to drain off, and also to permit an occasional scrubbing to keep it free from mold and putrefactive organisms. When the grain is first dropped it is spread in a layer about 6 or 8 inches deep and the steeping water is allowed to drain off for five or six hours. The grain is then heaped up in a pile, or couch as it is called, from 10 to 12 inches high. In about twenty-four hours the rootlets, at first resembling white points, force their way through the husks of the grain; these grow rapidly, and evolve heat which raises the temperature of the grain perceptibly. It is important that the temperature of the malt while on the floor be kept as near 60° F. as possible, or slightly below this temperature. To do this it is necessary to reduce the height of the piles gradually to about 3 inches and to turn the grain frequently, at least twice a day. A wooden shovel serves best for this purpose, as it is light, and permits the throwing of the grain high into the air, which greatly increases the vitality of the growing malt. Care should be taken not to crush the

grains during the turning, as crushed grains encourage the growth of mold, for which reason it is advisable to wear felt-soled shoes on the malting floor. After the grain has grown for from six to eight days the sprout, or "acrospire," which has been developing inside of the husk forces its way out at the end of the grain opposite to the rootlet. The malt may be used with excellent results at this time, but with a longer period of growth the diastatic power is considerably increased. The sprouting, therefore, is allowed to continue slowly for another six or eight days, or even longer, until the acrospire has attained a length three or four times that of the grain. The length of the rootlet and acrospire, however, do not necessarily indicate the quality of the malt, as the slower the growth and the longer the period of growing the higher will be the diastatic power, the extent of the growth being equal. The aim while the grain is on the floor is, therefore, to have it grow as slowly as possible without allowing it to wither. It may be sprinkled occasionally if necessary to keep it in a moist and healthy condition.

Figure 7 shows the different stages of the growing grain: (1) The grain as it leaves the steeping tank; (2) the rootlet breaking through the husk; (3 and 4) the development of the rootlet and sprout; (5) the sprout broken through the husk (at this point the grain has grown for a period of about six days); (6 and 7) the malt as it should appear after growing for fifteen or twenty days, at which time the diastatic power will be very high. After the last period the diastatic power will decrease, as the grain withers. In order to save labor the amount of barley required for two or three days' operation may be steeped and malted at the same time, as it may remain upon the floor a few days, more or less, without any appreciable change. If the malt has been properly handled it will have increased its original weight by about 50 per cent.

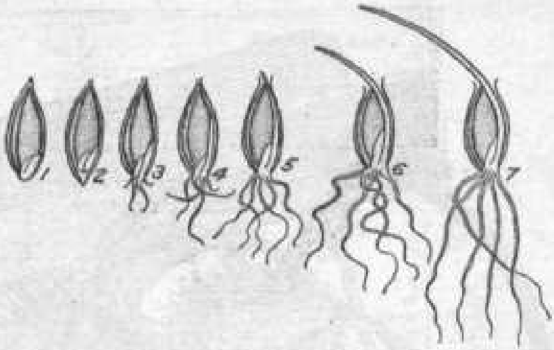

FIG. 7.—A sprouting grain of barley at different stages of development.

It is absolutely essential that the grain be turned at least twice a day from the time it is put on the floor until it is used. The malting room should be kept as near a constant temperature as possible, and so arranged as to allow sufficient ventilation and prevent strong drafts of air from coming in contact with the grain. It is preferable to have the floor below the level of the surface of the earth, about the depth of an ordinary cellar, so that its temperature will not be easily influenced by weather conditions. Briefly, then, a good barley malt can only be obtained from a good grade of barley properly steeped and grown for a long interval of time (twelve to twenty days) with a fair amount of moisture, at a temperature not to exceed 60° to 63° F.

CRUSHING THE GREEN MALT.

In order to get the benefit of the total amount of diastase developed it is necessary that the malt be thoroughly crushed; this should be done a short time before using. The crusher shown in figure 8 is of the type generally used. It is advisable to pass the malt through the crusher twice, in order to insure that it is completely crushed and the diastase released from the grains, thus permitting of its ready diffusion through the material upon which it is to act.

PREPARATION AND VALUE OF GREEN MALT FROM VARIOUS GRAINS.

While experience shows that barley is best suited for malting purposes, it may be necessary sometimes when it is not available to use other grains. The following table gives the details of preparation and the relative values of green malt made from other sources:

Preparation of green malt from various grains and their respective values.

Kind of grain.	Time required for steeping.	Temperature of steeping water.	Temperature maintained on floor.	Time required for sprouting.	Diastatic power.
	Hours.	°*F.*	°*F.*	*Days.*	
Barley	48–60	60	60	12–20	1,200–1,400
Wheat	36–48	55	60	8–16	800–1,000
Rye	15–24	55	60	8–16	300– 350
Oats	24–30	60	65	8–12	200– 250
Corn	72–96	70	75	8–10	100– 150

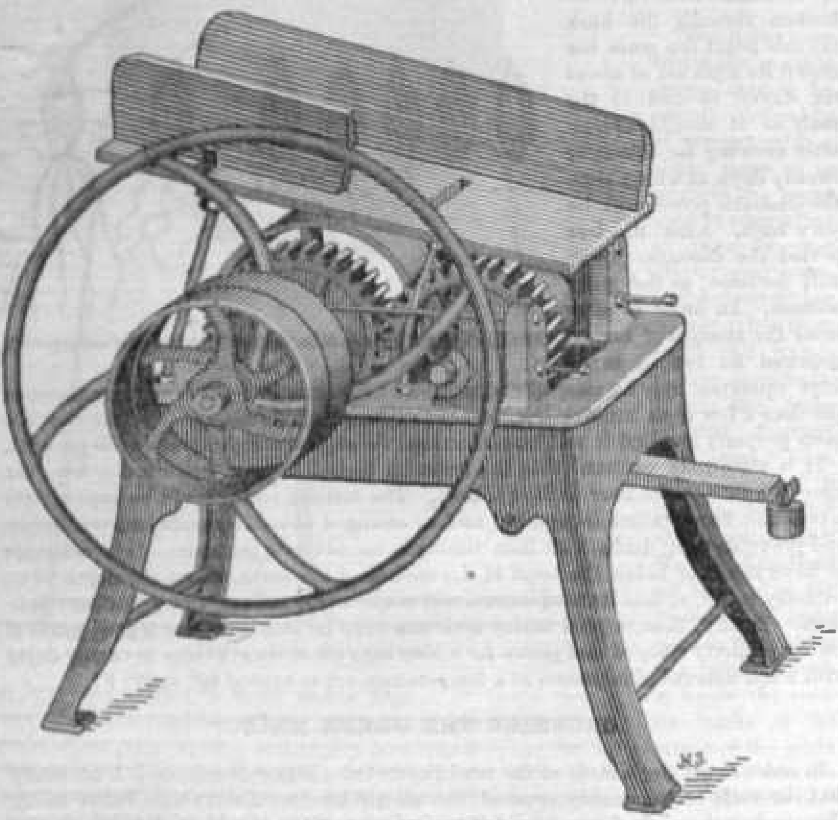

Fig. 8.—Green malt crusher.

The diastatic power, shown in the last column, is measured by allowing 1 cc of malt extract (25 grams of malt containing approximately 50 per cent of moisture to 500 cc of water digested for four hours at ordinary temperature) to act upon 100 cc

of a 2 per cent solution of soluble starch for one hour at room temperature. The amount of maltose is determined by weighing the copper oxid precipitated from Fehling's solution. The figures given under "diastatic power" represent the number of grams of maltose which 100 grams of malt will produce.

Wheat is the only grain that shows even a fair value as compared with barley; the others are not only markedly inferior in diastatic power but are also rather difficult to prepare, especially corn. For these reasons they are not to be considered as a possible source of malt at the present time. Barley is very easy to handle during the malting process, and as it can be obtained in most sections of the country it is generally used.

RELATIVE VALUE OF GREEN AND DRIED MALT.

A series of experimental mashes were run in which various amounts of green malt were allowed to act upon equal quantities of starch. The results obtained are given in the following table:

Results obtained on seven mashes using varying amounts of green malt.

Data.	Number of mash.						
	1.	2.	3.	4.	5.	6.	7.
Mash:							
Amount of malt (pounds)	3.2	3.72	3.92	4.3	5.12	5.4	5.67
Amount of potatoes (pounds)	160	160	160	160	160	160	160
Total mash (gallons)	20	20	20	20	20	20	20
Yeast mash added (gallons)	1	1	1	1	1	1	1
Set mash:							
Saccharimeter reading	17.6	17.6	17.4	17.6	17.5	17.7	17.7
Acidity (cc)	.7	.7	.7	.7	.7	.7	.7
Fermented mash:							
Saccharimeter reading	1.3	2.2	1.4	1.3	1.8	1.5	1.9
Acidity (cc)	.85	.85	.85	.8	.95	.95	1.6
Temperature during fermentation (°F.)	60–80	60–80	60–80	60–80	60–80	60–80	60–80
Reducing sugar in 100 cc (grams)	0.12	0.23	0.11	0.14	0.14	0.13	0.24
Starch (per cent)	.10	.38	.27	.26	.44	.49	.50
Alcohol by volume (per cent)	8.4	7.9	8.4	8.3	8.2	8.3	8.1

For mash No. 1, in which the smallest amount of green malt was used, the saccharimeter reading of the fermented mash is as low as that of any of the other mashes. The amount of reducing sugars and the percentage of starch present in the fermented mashes increase with the larger amount of malt used. This proves that all the starch contained in the potatoes was converted as completely in the mash containing the smallest amount of malt as in those for which considerably more was used, and that the starch and sugar present in the fermented mash was contained in the malt itself, and so held within it as to prevent its being acted upon during the fermentation. The high percentage of alcohol contained in mash No. 1 as compared with that of the others also indicates that this mash contained a sufficient amount of malt to completely convert its starch. In other words, 3.2 pounds of malt is enough to convert the starch in 160 pounds of potatoes, or about 2 pounds for each 100 pounds of potatoes. The potatoes used in these mashes contained 16 per cent of starch, so that each pound of malt converted 8 pounds of starch.

In large distilleries where corn is used in the manufacture of alcohol it is considered an economical practice to use 8 pounds of dried malt for each 100 pounds of corn. As corn contains approximately 60 per cent of starch it is seen that 1 pound of dried malt also converts about 8 pounds of starch, so that, pound for pound, the value of green and dried malt is about the same. The amount of green malt, however, which can be manufactured from a certain amount of barley is double that of dried malt, so that the cost of using the latter will be twice as much.

YEAST.[a]

DEVELOPMENT OF YEAST.

Yeast is an exceedingly small plant that grows and reproduces itself in liquids containing sugar. During its development it decomposes the sugar and forms alcohol by the process known as fermentation. It is generally seen in the shape of a compressed cake, consisting of a great number of minute cells, each of which is a distinct plant, capable of further reproduction, which has been separated from the liquid in which it was grown. The cells grow ordinarily by budding or sprouting, as shown in figure 9. The older or mother cells will bud and form young or daughter cells which cling to the parents for a time and then separate and become parent cells in their turn. Both parent and daughter cells continue to bud as long as there is any sugar in the liquid, and each one forms a new cell about every twenty minutes. Figure 10 shows the growth and reproduction of yeast cells as seen under the microscope, the cells being too small to be seen with the naked eye.

SPONTANEOUS AND PURE CULTURE YEASTS.

Yeast cells are blown about in the air, as is evidenced by the fact that they are found upon various fruits containing sugar. It is their presence that causes grape juice, cider, etc., to ferment. Also if a liquid which contains sugar, but in which there is no yeast, is exposed to the open air, fermentation will begin after several hours. This is due to the yeasts which have fallen into the liquid from the air and become active. Such a fermentation is called "spontaneous" or "wild yeast" fermentation because it takes place of its own accord and is distinguished from the so-called "pure-culture yeast fermentation" in that it can not be controlled.

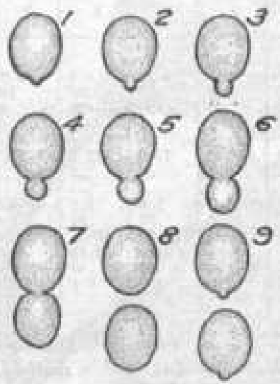

FIG. 9.—Development of a yeast cell.

Spontaneous fermentation can not be used in the practical manufacture of alcohol inasmuch as it can not be relied upon to take place in short and regular periods of time; it is therefore customary to add certain amounts of yeast. A hop yeast originating from cells in the air or a pure-culture yeast may be used. The latter is obtained by isolating a single cell of a yeast that has been found to be especially effective for alcoholic fermentation and cultivating it carefully so that it can be used as a start or seed yeast at any time. The term "pure culture" applies to the method of handling a yeast and not to any particular kind. If a single cell of any wild yeast is separated from all other organisms and allowed to grow in complete isolation, a yeast will be obtained which will have all the characteristics of the original single cell and is then known as a pure-culture yeast.

There are a great many varieties of yeasts, differing in value for the various commercial uses. Some are best suited for baking and others for fermenting purposes. The fermenting power of a yeast will also vary with the character of the liquid in which it is placed; therefore, when a yeast is found to be particularly suited for a special purpose, it is advisable to make a culture of it so that a start or seed yeast with the desired characteristics will always be available. The cultivation of a yeast does not necessarily improve its effectiveness, but simply permits the reproduction of the desired kind of yeast. A culture yeast with known characteristics may be used, therefore, with more certainty of uniformly good results than a spontaneous yeast.

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[a] Acknowledgment is made to R. E. Lee for assistance in the preparation of this chapter.

DEVELOPMENT OF A START YEAST.

Yeast culture is rather difficult, and as any quantity may be grown from one start yeast, it is best to obtain the initial yeast from a laboratory; if this is not convenient, a hop yeast may be grown, or as a last resource ordinary compressed baker's yeast may be used. It is not necessary, for fermentation purposes, to separate the yeast from the liquid in which it is grown, but the entire liquid, together with the yeast (known as the "yeast mash"), may be put into the liquid which is to be fermented. It requires a yeast mash of about 2 to 3 per cent by volume of the main mash (as the liquid to be fermented is called) to carry on the fermentation properly, so that the start yeast must be increased or grown by making preliminary yeast mashes, and increasing the volume ten times with each successive mash until the desired quantity is obtained. These mashes are prepared exactly like the one now to be described and may be made in any suitable wood or copper vessel.

If compressed yeast is used 1 pound will be sufficient to start a 20-gallon mash, and if culture yeast from a laboratory is used 1 gallon (which is the amount usually sold) will start a 10-gallon mash.

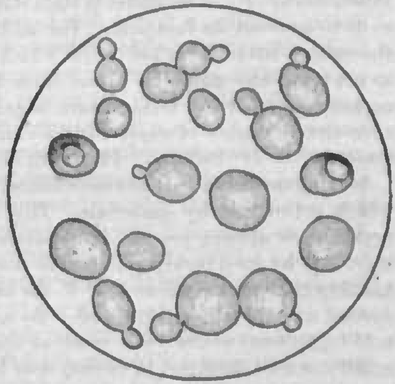

FIG. 10.—Growth of yeast in a liquid containing sugar as seen under the microscope.

PREPARATION OF A SPONTANEOUS HOP YEAST.

If a spontaneous hop yeast is to be used, it must be obtained in the following manner:

Boil 1 pound of hops in 5 gallons of water for fifteen minutes; strain off the hops and add 8 pounds of ground barley malt to the extract. Allow the mixture to stand about five hours, then strain it through a fine brass sieve to remove all the particles of grain, cool to about 85° F., and place in a warm room and hold at that temperature. The gravity of the liquid should be about 20° Balling. In about ten hours fermentation will begin and should be allowed to continue until the gravity has fallen to 6° or 8° Balling. The resulting spontaneous or hop yeast is then put into a tin-lined copper jug and kept on ice or in a cool place (preferably in running water or at the bottom of a well) at a temperature never exceeding 55° F., under which conditions it will keep indefinitely and a start yeast will be obtainable at any time. The jug is made absolutely air and water tight and provided with a faucet for withdrawing the yeast. The use of the quantities given will produce about 2 gallons of yeast, all or part of which may be used to start a yeast mash ten times the volume of the amount used.

YEAST MASHES.

Yeast will grow rapidly in a liquid containing sugar such as may be obtained in a potato or grain mash in which the starch of these materials is converted into sugar by the action of malt. Rye is most convenient for this purpose, as the malt will act upon its starch without the preliminary cooking, which is necessary in the case of potatoes. As there are many organisms besides yeast that feed upon sugar and are not only incapable themselves of producing alcohol, but are also decidedly harmful to the development of the yeast, it is extremely important that such precautions be taken as will prevent these injurious organisms from developing in the mash, and that conditions be made favorable for the rapid growth of the yeast. This is accomplished,

first, by allowing the mash to sour, or in other words to increase its natural acidity, which is not harmful to the development of the yeast but is decidedly so to most other organisms; second, by adding a sufficient amount of yeast to carry the fermentation through before the other organisms can be established. These operations are known as souring and yeasting the mash. The details of preparing a grain yeast mash are given in the following section:

Preparation of a Grain Yeast Mash.

The yeast mash is prepared in a wooden tub equipped with a rake for stirring and a copper coil fitted with steam and water connections for heating and cooling the mash as shown in figure 1. The volume, as has already been stated, should be from 2 to 3 per cent of the main mash to be fermented and 10 times that of the yeast mash used to start it. Equal parts by weight of finely ground rye meal and crushed green malt (or ground dried malt) are added to water in the proportion of 1 quart of water to each pound of the grain used. The water is measured into the tub and the temperature raised to 150° F. The stirrer is then started and the rye meal allowed to run in slowly so as to prevent its lumping. The addition of the rye will cause the temperature of the mash to fall to about 140° F., at which point the malt is added. The malt is allowed to act upon the starch for about three hours, during which time the mash is stirred occasionally and the temperature is gradually raised to 145° F. At the end of this time the formation of sugar will be complete and the gravity of the mash should be about 20° to 24° Balling. The mash is then ready to be soured.

Souring the mash.—It has been found that acid solutions tend to suppress organisms which infect starchy materials. This is especially true of lactic acid and as this organism is always present in potatoes and grain the acidity of the mash can be increased by its development under the proper conditions. This is accomplished by keeping the yeast mash at 130° F. for forty-eight hours, at the end of which time the desired acidity will be obtained. By adding a start sour (that is, a culture of lactic-acid organisms) to the yeast mash at the beginning of the souring period, the proper acidity can be obtained in twenty-four hours, so that a forty-eight hour period is only necessary in the case of the first yeast mash or if a new sour is desired. The start sour is a portion of a previously soured yeast mash and should be about 2 per cent of the yeast mash to which it is added. It is important that the proper temperature be maintained throughout the souring period in order to prevent the growth of other acid organisms which interfere with the development of the yeast.

The acidity of the mash (determined as explained on page 14) at the beginning of the souring period is called its natural acidity and in a mash prepared as described will be about 0.5 cc. By adding a start sour the acidity will increase in twenty-four hours to about 2.5 or 3 cc, when the start sour for the following day's mash is withdrawn. An acidity of 2.5 or 3 cc will be sufficient to suppress all undesirable organisms and will not interfere with the proper development of the yeast. Further growth of the lactic acid organisms which have now produced the desired acidity must be prevented by heating the mash to 160° F. and maintaining this temperature for twenty minutes. The mash is then cooled, by passing cold water through the coil, to a temperature favorable to the growth of the yeast (see following caption). It is very important that the cooling be done as quickly as possible as there are a great many objectionable organisms which develop at the warmer temperatures.

Yeasting the mash.—When the temperature has been reduced to approximately 90° F., the yeast (about 10 per cent by volume of the mash) is added; it may be either a preliminary yeast mash or a quantity of mash taken from the previous day's yeast mash, the former being the case when the distillery is just being put into operation, or when a new yeast is desired, and the latter when the plant is running regularly. The temperature is then further reduced to about 60° to 70° F. This final temperature is

called the "setting temperature" and varies with the volume of the mash and the weather conditions. It should be such as will permit the immediate growth of the yeast. Gas bubbles, due to the escape of carbonic-acid gas, appearing on the surface of the mash after a few hours will indicate that the yeast has become active. The fermentation, which will gradually become more vigorous, is allowed to continue for twenty-four hours. As the activity of the yeast increases, the temperature of the mash will rise perceptibly, but it should not be allowed to go above 90° F., as there will then be danger of the yeast mash becoming infected with other organisms, such as acetic bacteria, which have a harmful effect on the fermentation.

The yeast in the yeast mash should be active and vigorous when put into the main mash so that fermentation will begin at once. The yeast remains active only so long as there is sugar present for its growth, consequently the yeast mash is added to the main mash before all the sugar in the former is exhausted or when its gravity has fallen to about 4° or 5° Balling. If it is allowed to fall below this point the yeast will become less vigorous from lack of food and delay fermentation of the main mash.

The setting temperature, as well as that maintained during the twenty-four-hour fermentation period, should be as low as possible and still permit a sufficient growth of the yeast to cause the gravity to fall to 4° or 5° Balling. The acidity of the yeast mash should be carefully taken after the souring period, or rather immediately after the mash has been yeasted, and compared with that of the mash twenty-four hours later, namely, after the fermentation period. Not much change should occur as any increase would indicate the presence and development of undesirable acid organisms, the immediate suppression of which is of great importance. They can be easily avoided by employing only the proper temperatures and keeping the tubs sweet and clean. It is best to cover the tubs, thoroughly sterilize them with live steam, and scrub them with clean water after each use. The acidity and gravity of the fermented mash having been found to be satisfactory, a quantity amounting to about 10 per cent by volume of the yeast mash to which it is to be added is removed and kept at a temperature below 55° F., to be used as a start yeast for the following yeast mash, and the rest is added to the main mash. Summarizing this discussion, it is seen that a yeast mash consists of a selected yeast grown in a suitable mash and requires about fifty-one hours for its preparation, of which three hours are required to allow the malt to act upon the starch, twenty-four for souring the mash, and twenty-four for growing the yeast.

Preparation of a Potato Yeast Mash.

The selection of a yeast and its subsequent development in the mash as just described will be applicable to either a grain or a potato distillery. It will be found more economical, however, in the latter to use rye in the first two or three yeast mashes and then substitute potatoes. A part of each day's cooked and malted potatoes constituting the main mash is pumped into the yeast tub and one-half pound of crushed green malt or one-quarter of a pound of dried malt is added for each gallon of potato mash, this additional malt being added to serve as food for the yeast. It is not necessary to add water. To the malted potato yeast mash is added a start sour taken from a previously soured potato or grain mash, and after twenty-four hours it is yeasted by adding a start yeast taken from a previous grain or potato yeast mash. Exactly the same operations are employed and the same temperatures maintained as in the case of the grain yeast mash just described. An economical potato-distilling yeast may be obtained, therefore, by the growth of an initial start yeast in a grain mash, the use of grain yeast mashes for the first two or three days' operations, and the subsequent substitution of potatoes for rye in the yeast mashes. The accompanying schedule outlines the various steps necessary in the building up and daily preparation of a potato-distillery yeast.

Working schedule for operator of distillery.

Number of mash.	(1) Saturday.	(2) Sunday.	(3) Monday.	(4) Tuesday.	(5) Wednesday.	(6) Thursday.
Preliminary yeast mash.	Make 10 gal. grain mash. Hold at 130° F. to sour.	Hold at 130° F. to sour.	Heat to and hold at 160° F. for twenty minutes. Cool to setting temperature and add 1 gal. start yeast purchased.	Add total mash to yeast mash No. 1.		
Yeast mash No. 1		Make 50 gal. grain yeast mash. Hold at 130° F. to sour.	Hold at 130° F. to sour.	Remove 1 gal. mash to sour yeast mash No. 2. Heat to and hold at 160° F. for twenty minutes. Cool to setting temperature and add 10 gal. preliminary yeast.	Remove 10 gal. mash to use as start yeast for yeast mash No. 2, and add balance to main mash No. 1 in fermenter.	
Main mash No. 1					Mash 8,000 lbs. potatoes, 400 lbs.=50 gal. being used for yeast mash No. 3, and 7,600 lbs.=950 gal. delivered to fermenter.	Fermenting.
Yeast mash No. 2				Make 50 gal. grain yeast mash. Add 1 gal. sour mash removed from yeast mash No. 1. Hold at 130° F. to sour.	Remove 1 gal. mash to sour yeast mash No. 3. Heat to and hold at 160° F. for twenty minutes. Cool to setting temperature and add 10 gal. start yeast removed from yeast mash No. 1.	Remove 10 gal. mash to use as start yeast for yeast mash No. 3, and add balance to main mash No. 2 in fermenter.
Main mash No. 2						Mash 8,000 lbs. potatoes, 400 lbs.=50 gal. being used for yeast mash No 4, and 7,600 lbs.=950 gal. delivered to fermenter.

Yeast mash No. 3					400 lbs.—50 gal. potato mash taken from main mash No. 1. Add 1 gal. sour mash removed from yeast mash No. 2. Hold at 130° F. to sour.	Remove 1 gal. mash to sour yeast mash No. 4. Heat to and hold at 160° F. for twenty minutes. Cool to setting temperature and add 10 gal. start yeast removed from yeast mash No. 2.
Main mash No. 3						
Yeast mash No. 4						400 lbs.—50 gal. potato mash taken from main mash No. 2. Add 1 gal. sour mash removed from yeast mash No. 3. Hold at 130° F. to sour.
Main mash No. 4						
Yeast mash No. 5						
Main mash No. 5						
Yeast mash No. 6						
Main mash No. 6						
Yeast mash No. 7						
Main mash No. 7						

Working schedule for operator of distillery—Continued.

Number of mash.	(7) Friday.	(8) Saturday.	(9) Sunday.	(10) Monday.	(11) Tuesday.	(12) Wednesday.
Preliminary yeast mash.						
Yeast mash No. 1						
Main mash No. 1	Fermenting	Distilled				
Yeast mash No. 2						
Main mash No. 2	Fermenting	Fermenting	Fermenting	Distilled		
Yeast mash No. 3	Remove 10 gal. mash to use as start yeast for yeast mash No. 4, and add balance to main mash No. 3 in fermenter.					
Main mash No. 3	Mash 7,600 lbs. potatoes, and deliver total mash to fermenter. No yeast mash made.	Fermenting	Fermenting	Fermenting	Distilled	
Yeast mash No. 4	Remove 2 gal. mash to sour yeast mashes Nos. 5 and 6. Heat to and hold at [illegible]° F. for twenty minutes. Cool to setting temperature and add 10 gal. start yeast removed from yeast mash No. 3.	Remove 10 gal. mash to use as start yeast for yeast mash No. 5, and add balance to main mash No. 4 in fermenter.				
Main mash No. 4		Mash 8,400 lbs. potatoes, 400 lbs.=50 gal. being used for yeast mash No. 5, 400 lbs.=50 gal. used for yeast mash No. 6, and 7,600 lbs.=950 gal. delivered to fermenter.	Fermenting	Fermenting	Fermenting	Distilled.

Yeast mash No. 5		400 lbs.=50 gal. potato mash taken from main mash No. 4. Add 1 gal. sour mash removed from yeast mash No. 4. Hold at 130° F. to sour.	Heat to and hold at 160° F. for twenty minutes. Cool to setting temperature and add 10 gal. start yeast removed from yeast mash No. 4.	Remove 10 gal. mash to use as start yeast for yeast mash No. 6 and add balance to main mash No. 5 in fermenter.		
Main mash No. 5				Mash 8,000 lbs. potatoes, 400 lbs.=50 gal. being used for yeast mash No. 7 and 7,600 lbs.=950 gal. delivered to fermenter.	Fermenting	Fermenting.
Yeast mash No. 6		400 lbs.=50 gal. potato mash taken from main mash No. 4. Add 1 gal. sour mash removed from yeast mash No. 4. Hold at 130° F. to sour.	Hold at 130° F. to sour	Remove 1 gal. mash to sour yeast mash No. 7. Heat to and hold at 160° F. for twenty minutes. Cool to setting temperature and add 10 gal. start yeast removed from yeast mash No. 5.	Remove 10 gal. mash to use as start yeast for yeast mash No. 7, and add balance to main mash No. 6 in fermenter.	
Main mash No. 6					Mash 8,000 lbs. potatoes, 400 lbs.=50 gal. being nsed for yeast mash No. 8; 7,600 lbs.=950 gal. delivered to fermenter.	Fermenting.
Yeast mash No. 7				400 lbs. potatoes=50 gal. potato mash taken from main mash No. 5. Add 1 gal. sour mash removed from yeast mash No. 6. Hold at 130° F. to sour.	Remove 1 gal. mash to sour yeast mash No. 8. Heat to and hold at 160° F. for twenty minutes. Cool to setting temperature and add 10 gal. start yeast removed from yeast mash No. 5.	Remove 10 gal. mash to use as start yeast for yeast mash No. 8, and add balance to main mash No. 7 in fermenter.
Main mash No. 7						Mash 8,000 lbs. potatoes, 400 lbs.=50 gal. being used for yeast mash No. 9; 7,600 lbs.=950 gal. delivered to fermenter.

ANALYTICAL DATA.

In connection with the experiments on potatoes in the distillery certain analytical data were obtained in the laboratory, which are of considerable interest, as they show the composition of the original material used and also of the by-products obtained.

COMPOSITION OF THE WHOLE POTATOES.

In the first table are given the analytical results obtained for the various lots of potatoes used. A complete analysis of these potatoes was made in order to compare their composition with that of the mash at its various stages. In distillery practice, however, the chief determinations of value are the sugar and starch, as these constituents determine the value of potatoes for the manufacture of alcohol.

Special attention is called to the analysis of the potatoes used in mash No. 31. These were small unmarketable culls, averaging not more than 1 inch in diameter, and were found to contain 14.5 per cent of starch, which is as much and more than was found in some of the other potatoes that were of a size and grade ordinarily used for eating purposes. The analyses of the potatoes were also calculated to a moisture-free basis in order that the composition of their dry material might be readily compared with that of the fermented mash or slop.

Analysis of potatoes.

BASED ON ORIGINAL MATERIAL.

Mash.	Total solids.	Ash.	Protein (N × 6.25.)	Ether extract.	Sugars as dextrose.		Starch.		Crude fiber.	Nitrogen-free.
					Before inversion.	After inversion.	By diastase.	Calculated from solids by Maercker's table.		
	Per ct.	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*
No. 14	22.70	....	2.45	0.10	0.39	0.39	16.4	16.9	0.53	2.83
No. 15	21.30	....	....	....	.64	.64	15.8	15.5	....	....
No. 16	21.57	....	....	....	.32	.40	15.4	15.8	....	....
No. 17	21.90	....	....	....	.46	.46	16.2	16.2	....	....
No. 19	20.50	0.85	2.02	.03	.80	1.06	14.4	14.7	.51	1.68
No. 21	20.38	.80	2.31	.03	.72	.91	13.7	14.5	.50	2.13
No. 22	20.62	.80	2.33	.04	Trace	Trace	13.9	14.9	.50	3.05
No. 23	19.96	.90	1.75	.02	.27	.41	14.0	14.2	.37	3.42
No. 25	20.00	.92	2.08	.09	.26	.38	13.6	14.3	.38	2.55
No. 26	21.70	1.08	2.19	.08	.20	.20	15.2	16.0	.42	2.53
No. 27	21.33	1.05	2.19	.08	.18	.18	14.6	15.5	.49	2.75
No. 29	19.60	1.02	2.13	.09	Trace	Trace	13.7	13.8	.41	2.25
No. 30	19.20	1.01	2.04	.08	Trace	Trace	13.7	13.5	.49	1.88
No. 31	20.20	1.10	1.58	.06	.43	.43	14.1	14.5	.61	2.32
Average	20.78	.96	2.09	.06	.33	.30	14.6	15.0	.47	2.19
MOISTURE-FREE BASIS.										
No. 14	....	....	10.79	0.44	1.72	1.72	72.25	....	2.33	12.46
No. 15	....	....	....	....	3.00	3.00	74.18	....	....	....
No. 16	....	....	....	....	1.48	1.85	71.39	....	....	....
No. 17	....	....	....	....	2.10	2.10	73.97	....	....	....
No. 19	....	4.15	9.85	.15	3.90	5.17	70.24	....	2.49	7.95
No. 21	....	3.93	11.33	.15	3.53	4.47	67.22	....	2.45	10.45
No. 22	....	3.88	11.29	.19	Trace	Trace	67.41	....	2.42	14.79
No. 23	....	4.96	8.77	.10	1.35	2.05	70.14	....	1.85	17.13
No. 25	....	4.66	10.40	.45	1.30	1.90	68.00	....	1.90	12.75
No. 26	....	4.98	10.90	.36	.92	.92	70.04	....	1.94	11.65
No. 27	....	4.92	10.26	.37	.84	.84	68.45	....	2.29	12.89
No. 29	....	5.20	10.86	.46	Trace	Trace	69.89	....	2.09	11.47
No. 30	....	5.26	10.62	.42	Trace	Trace	71.35	....	2.55	9.79
No. 31	....	5.45	7.82	.20	2.13	2.13	69.80	....	3.02	11.48
Average	....	4.69	10.06	.29	1.59	1.88	70.35	....	2.26	10.55

Purchase on Basis of Starch Content.

The results given in the table indicate clearly that it will be necessary to buy potatoes for making alcohol, not by weight, but on the basis of their starch content. The difference in the value of potatoes for alcohol-making is illustrated by comparing the starch content of the potatoes of mash No. 14, i. e., 16.9 per cent, with that of mash

No. 30, i. e., 13.5 per cent. In a ton of potatoes containing 16.9 per cent of starch there would be 338 pounds of starch, while in the same amount of potatoes containing 13.5 per cent of starch there would be only 270 pounds, a difference of 68 pounds. Since 1 pound of starch will yield 0.079 gallon of 90 per cent alcohol, the 68 pounds would yield 5.37 gallons, which at 40 cents a gallon would be worth $2.15. That is, the first lot of potatoes would be worth $2.15 more per ton for the production of alcohol than the second lot. It can be readily seen that success or failure might depend on the basis upon which the potatoes were bought.

Simple Method of Determining Starch.

To establish an accurate but shorter method than that of actual analysis for obtaining the starch content of potatoes, a determination of the solids by drying at 100° C. was made on 14 samples and from it the starch content was calculated by Maercker's table.[a] This calculation gave 15 per cent of total starch, while the average result of the 14 analyses was 14.99 per cent of sugar and starch, proving conclusively that for factory practice in buying potatoes on the starch content, this method of determination is entirely satisfactory. Whether the still more simple method of determining the specific gravity of the potatoes is sufficiently accurate has not yet been decided. The determination of solids requires some chemical knowledge, while the apparatus for obtaining the starch content from the specific gravity has been so simplified as to give a very rapid and easy method, and if accurate enough it will have many advantages over the other methods because of the fact that a person without any chemical training can use it.

ANALYSIS OF POTATO SKINS.

The composition of the material separated by the peel extractor, consisting of the skin and fibrous or woody portions of the potato, which were not disintegrated during the cooking process, is shown in the following table. The results obtained are extremely interesting, showing how much richer this material is in proteins and how much poorer in starch than the whole potato. This illustrates the well-known fact that the protein of the potato is in a layer close to the skin.

Analysis of potato skins (extracted from the mash by peel extractor).

BASED ON ORIGINAL MATERIAL.

Mash.	Total solids.	Ash.	Protein (N×6.25)	Ether extract.	Sugar as dextrose.	Starch by diastase.	Crude fiber.	Nitrogen-free.	Percentage of total potatoes.
	Per ct.	*Per ct.*	*Per cent.*	*Per ct.*	*Per cent.*	*Per cent.*	*Per ct.*	*Per cent.*	
No. 19	32.2	1.99	6.10	0.96	1.83	0.90	8.17	12.25	....
No. 21	32.9	1.74	10.80	.81	.20	2.40	7.53	9.42	....
No. 22	26.2	1.39	7.52	.73	.21	1.70	5.55	9.10	2.49
No. 23	35.0	2.15	6.76	.76	.35	2.18	6.70	16.10	1.93
No. 25	30.7	1.86	5.99	.75	.39	1.70	5.65	14.36	1.94
No. 26	27.9	1.90	5.59	.55	.33	2.89	4.63	12.01	2.02
No. 27	24.8	1.66	5.20	.55	.28	3.00	5.18	8.93	2.30
No. 29	24.8	1.92	5.24	.63	.24	2.43	5.38	8.96	1.72
No. 30	22.1	1.74	4.58	.46	.28	2.50	4.49	8.05	2.33
No. 31	23.6	1.65	3.92	.66	.12	2.90	4.82	9.53	3.69
Average	28.0	1.81	6.13	.71	.43	2.26	5.79	10.87	2.30

MOISTURE-FREE BASIS.

Mash.	Total solids.	Ash.	Protein (N×6.25)	Ether extract.	Sugar as dextrose.	Starch by diastase.	Crude fiber.	Nitrogen-free.	Percentage of total potatoes.
	Per ct.	*Per ct.*	*Per cent.*	*Per ct.*	*Per cent.*	*Per cent.*	*Per ct.*	*Per cent.*	
No. 19	....	6.18	18.94	2.98	5.67	2.79	25.37	38.07	....
No. 21	....	5.29	32.83	2.47	.59	7.29	22.89	28.64	....
No. 22	....	5.29	28.65	2.77	.82	6.48	21.15	34.84	....
No. 23	....	6.14	19.31	2.17	.99	6.23	19.14	46.02	....
No. 25	....	6.06	19.51	2.44	1.27	5.53	18.40	46.79	....
No. 26	....	6.79	19.98	1.97	1.19	[b] 10.33	16.55	43.19	....
No. 27	....	6.70	20.96	2.23	1.15	[b] 12.10	20.91	35.95	....
No. 29	....	7.75	21.12	2.52	.96	[b] 12.11	21.69	33.85	....
No. 30	....	7.90	20.76	2.09	1.26	[b] 11.30	20.35	36.34	....
No. 31	....	7.00	16.63	2.82	.53	[b] 12.30	20.46	40.26	....
Average	....	6.51	21.87	2.55	1.44	8.65	20.69	38.40	....

[a] Handbuch der Spiritusfabrication, p. 176.

[b] Sample taken before complete malting.

The average of the analyses, calculated to a water-free basis, shows that the skins contained 21.87 per cent of protein and 8.65 per cent of starch as compared with 10.06 per cent of protein and 70.31 per cent of starch in the whole potato. The skins are also much richer in fat. This shows that weight for weight the skins are much more valuable as a cattle food than the whole potato. On the other hand, the loss of alcohol-producing material by separating the skins from the mash is very slight, as they average only 2.3 per cent of the whole potato.

COMPOSITION OF THE POTATO SLOP.

The following table, giving the composition of the slop or residue of the mash after the alcohol has been removed, is exceedingly interesting as it shows the value of this important by-product as a cattle food:

Analysis of potato slop.

BASED ON ORIGINAL MATERIAL.

Mash.	Total solids.	Ash.	Protein (N×6.25).	Ether extract.	Sugar as dextrose.	Starch.	Crude fiber.	Nitrogen-free extract
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
No. 15	6.90	....	2.26	....	0.17	0.29	0.70	3.40
No. 21	7.17	0.67	1.97	0.04	.21	.15	.52	3.61
No. 21	5.80	.69	1.91	.08	.06	.10	.58	2.38
No. 23	5.90	.72	1.68	.04	.14	.27	.46	2.59
No. 25	7.22	.84	2.05	.01	.17	.16	.47	3.52
Average	6.50	.73	1.97	.04	.15	.19	.55	2.96

MOISTURE-FREE BASIS.

Mash.	Total solids.	Ash.	Protein (N×6.25).	Ether extract.	Sugar as dextrose.	Starch.	Crude fiber.	Nitrogen-free extract
No. 15	....	....	32.75	....	2.46	4.20	10.14	50.45
No. 21	....	9.30	27.47	0.56	2.93	2.10	7.25	50.39
No. 22	....	11.90	32.93	1.38	1.34	1.72	10.00	40.73
No. 23	....	12.20	28.47	.08	2.37	4.58	7.79	43.91
No. 25	....	11.63	28.39	.14	2.35	2.22	6.50	48.77
Average	....	11.26	30.00	.69	2.29	2.98	6.54	46.24

A comparison of the composition of the dry material of the whole potato, the potato skins, and the slop, using the averages of the three preceding tables is here made:

Comparative average analyses of potatoes, the skins, and the slop.

Material.	Ash.	Protein (N × 6.25).	Ether extract (fat).	Sugar as dextrose.	Starch.	Crude fiber.	Nitrogen-free extract.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Potato	4.39	10.06	0.29	1.50	70.35	2.26	10.55
Potato skins	6.51	21.87	2.55	1.44	8.65	20.69	38.40
Slop	11.26	30.00	.69	2.29	2.98	6.54	46.24

This table shows that the dry substance in the slop is very different in composition from the potato itself, being a more highly nitrogenous food. The great increase in the amount of protein as compared with the total dry substance in the slop is, of course, due to the fermentation of the starch and sugar, resulting in a concentration of the nitrogenous material. The actual value of slop as a food for cattle is discussed under the following caption.

SLOP FEEDING.[a]

GENERAL DISCUSSION.

Any scheme for the operation of agricultural distilleries, whether small or large, should provide for the utilization of the by-product

[a] This chapter, with the exception of the formulas for rations, was prepared by H. E. Sawyer.

known as "slop." This is the residuum remaining after the alcohol and a small amount of water have been boiled off from the fermented distillery mash; and it contains, dissolved or suspended in the remaining liquid of the mash, all of the constituents of the materials employed except that portion of the sugars and starch which was converted into alcohol during the fermentation. This slop has been found, both in this country and abroad, to be a feeding stuff of high value and should be fed to the stock on the farm that furnishes the raw materials used in the distillery. In this way its full utilization can be secured. First, through the production of flesh, milk, or energy in the stock to which it is fed; and, second, by returning to the soil in the form of manure those necessary elements of plant food which were abstracted during the production of the potatoes or other raw materials.

The chemical composition of feeding stuffs and the special functions of their different constituents are discussed fully in various accessible publications which deal with the principles and practice of cattle feeding.[a] Therefore, it will be assumed in the following paragraphs that the reader is familiar with the terms in which the composition of such materials is stated—such, for example, as moisture, ash, protein, fat, carbohydrates, sugars, starch, pentosans, and fiber—and with the significance of such expressions as coefficient of digestibility, calorific value, production value, and nutritive ratio, which it will be necessary to use in discussing the nutritive value of slop and the way in which it should be used as part of a properly balanced daily ration.

COMPARISON OF GRAIN AND POTATO SLOPS.

Since the chemical constituents of distillery slop are essentially identical with those of the distiller's raw materials, save for a diminution in the proportions of fermentable carbohydrates, and since different kinds of raw material vary greatly in their typical compositions, it follows that the composition and the nutritive value of slop will be dependent on the selection of raw materials and will vary considerably according to the nature of the latter. This is well illustrated by the following examples, drawn from the records of the Department's experimental distillery for the season of 1909.

Example No. 1.

Grain mash; fermentation, Serial No. 4.

Mash contained 1,680 pounds of maize, 100 pounds of rye, and 350 pounds of dry malt, all of the rye and 100 pounds of the malt being used in preparing the yeast mash. The volume of the main mash, about 1,000 gallons, yielded 175 proof gallons of alcohol and about 1,000 gallons of slop.

[a] The Feeding Value of Cereals: U. S. Dept. Agr., Bureau of Chemistry, Bul. 120. The Feeding of Farm Animals: U. S. Dept. Agr., Farmers' Bul. 22. The Computation of Rations for Farm Animals by the Use of Energy Values: U. S. Dept. Agr., Farmers' Bul. 346.

Example No. 2.

Potato mash; fermentation, Serial No. 31.

Mash contained 4,760 pounds of potatoes and 115 pounds of green malt, 320 pounds of the potatoes and 25 pounds of the malt being used in making the yeast mash. The volume of the main mash, about 625 gallons, yielded 101.4 proof gallons of alcohol and about 625 gallons of slop.

The composition of the raw materials used in these two mashes was as follows:

Chemical composition of raw materials used in mashes.

Materials.	Moisture.	Protein.	Fat.	Nitrogen-free extract.	Fiber.	Ash.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Maize	11.3	8.9	4.1	72.4	1.9	1.4
Rye	9.4	10.7	1.9	74.0	1.9	2.1
Dry malt	7.3	11.3	2.0	71.2	5.6	2.6
Green malt	42.0	12.3	.8	35.9	6.1	2.9
Potatoes	79.8	1.6	.1	16.9	.0	1.0

The 1,000 gallons comprising mash No. 1 contained 2,130 pounds of air-dry grain, representing 1,903 pounds of dry substance of the following composition:

	Pounds.
Protein	199.5
Fat	77.6
Nitrogen-free extract	1,539.0
Fiber	52.9
Ash	34.0
Total	1,903.0

It may be assumed that every proof gallon of alcohol obtained from this mash represented the decomposition of 6.4 pounds of nitrogen-free extract, calculated as starch. As 175 gallons were produced, it will be seen that 1,120 pounds of solids in the form of nitrogen-free extract must have disappeared during the fermentation, leaving in the slop 419 pounds of nitrogen-free extract and 783 pounds of dry solids, equivalent to 41.1 per cent of the total dry solids of the materials mashed.

In the case of example No. 2, 625 gallons of mash contained 4,760 pounds of potatoes and 115 pounds of green malt, representing 1,028 pounds of total dry substance, divided as follows:

	Pounds.
Protein	90.4
Fat	5.7
Nitrogen-free extract	845.7
Fiber	35.5
Ash	50.9
Total	1,028.2

This mash yielded 101.4 proof gallons of alcohol, consuming 6.4 pounds of starch per gallon; therefore 649 pounds of starch must have disappeared during fermentation, leaving 197 pounds of nitrogen-free extract and 379 pounds of total dry substance in the slop, equivalent to 37 per cent of the original dry substance in the mash.

A comparison of the composition of the two slops is facilitated by the conversion of the amounts of the several constituents into percentages on the dry basis, as shown in the following tabulation:

Percentage composition of grain and potato slops.

[Calculated to dry basis.]

Determinations.	Grain slop.	Potato slop.
	Per cent.	*Per cent.*
Protein	25.5	23.9
Fat	9.9	1.5
Nitrogen-free extract	53.5	52.0
Fiber	6.7	9.3
Ash	4.4	13.3
Total	100.0	100.0

These figures show a marked difference between the two slops, the potato slop being 8.4 per cent lower in fat and 8.9 per cent higher in ash than that from the grain. A further difference, not shown by the table, exists in the nature of the various nitrogenous constituents which are grouped under the term "protein." About 94 per cent of the nitrogen compounds present in maize slop are of true protein nature, having a high nutrient value, whereas only 71 per cent of the nitrogen of the potato slop is in the form of protein, the balance being present as amido compounds which are practically worthless as food. In two respects, therefore, potato slop is inferior to that obtained from grain, it is deficient in fat and in true protein. Notwithstanding this, however, it is a feeding stuff of decided value.

COEFFICIENTS OF DIGESTIBILITY.

To estimate the feeding value of slop there must be known, in addition to the composition of its dry substance, the extent to which its several constituents can be digested and utilized by the animals to which it may be fed. This factor, which is called the coefficient of digestibility, varies with the nature of the constituents and with the kind of animals fed[a] and can be obtained only by very careful feeding experiments, such as have been conducted by Kellner at the Möckern experiment station. The values given are based on his results.[b]

Coefficients of digestibility of slop.

Constituents.	Maize.	Potatoes.
	Per cent.	*Per cent.*
Protein	65	50
Fat	95	95
Extract	71	71
Fiber	50	20

With the aid of these factors, it is ascertained that 100-pound portions of dry substance from maize slop and potato slop contain respectively the following amounts of digestible nutrients:

Weights of digestible nutrients in 100 pounds of dry slop substance.

Digestible constituents.	Maize slop.	Potato slop.
	Pounds.	*Pounds.*
Protein	16.6	11.9
Fat	9.4	1.4
Extract	38.0	36.9
Fiber	3.4	1.9
Total	67.4	52.1

[a] U. S. Dept. Agr., Bureau of Chemistry Bul. 120, p. 8.

[b] Kellner, Die Ernährung der landwirthschaftlichen Nutztiere, 1905, pp. 564–570.

PRODUCTION VALUES.

By the use of another set of factors [a] it is possible to calculate approximately what weight of flesh will be gained by cattle to which definite rations of slop solids are being fed. The most important of these are given in the table.

Production value of food nutrients.

Nutrients.	Flesh gained by mature fattening oxen per 100 pounds of nutrient.
	Pounds.
Protein	23.5
Fat	52.6
Extract and fiber	24.8

The weights of the individual nutrients in 100 pounds of dry slop substance, multiplied by the appropriate factors from the foregoing table, give the flesh-producing capacities of the amounts of the several nutrients present; and the sum of these products indicates the flesh-producing value of the 100 pounds of slop solids. In the case of the two slops under discussion these values will be as follows:

Flesh-producing capacities of 100 pounds of slop solids.

Nutrients.	Maize slop.	Potato slop.
	Pounds.	*Pounds.*
Protein	3.9	2.8
Fat	4.9	.7
Carbohydrates	10.3	9.6
Total	19.1	13.1

Knowing the weight of the solids in a single gallon of slop, the flesh-producing capacity of any volume of the slop can be calculated by these values. Thus a gallon of maize slop, which contains 0.783 pound of dry solids, will have a flesh-producing capacity of 0.15 pound (0.783 × 0.191). The corresponding value for potato slop, containing 0.606 pound of dry substance per gallon, will be 0.08 pound (0.606 × 0.131). Thus, it is seen that the feeding value of this maize slop is approximately twice that of the potato slop and that 2 gallons of the latter would have to be fed to provide the amount of nutrients contained in a single gallon of the former.

NUTRITIVE RATIO.

In addition to the production values, which have just been discussed, another point relating to the nutrient qualities of slop remains to be considered, namely, the balance between the nitrogenous and non-nitrogenous constituents. This relation, which is called the "nutritive ratio," expresses the proportion between those elements of a food which are fitted respectively to produce muscular tissues on the one hand and fat, body heat, and energy on the other. This ratio is obtained numerically by multiplying the percentage of digestible fat by 2.25, adding the product to the aggregate percentage of digestible carbohydrates, and dividing the sum by the percentage of digestible protein. If the ratio is small (1:3 to 1:7) it is termed "narrow." If it is large (1:8 to 1:12) it is termed "broad." Maize is an example of a broad ratio and oats of a narrow one, the former being a heat-producing food with a ratio of 1:12.3, and the latter a tissue-forming food whose ratio is 1:5.8. [b]

[a] U. S. Dept. Agr., Bureau of Chemistry Bul. 120, p. 14.
[b] U. S. Dept. Agr., Bureau of Chemistry Bul. 120, p. 16.

The significance of the nutritive ratio is this: Fats and carbohydrates are not adapted to the formation of lean meat, which is distinctively a nitrogenous tissue; and at the same time protein is not a good energy-producing food, although a certain amount of it is indispensable in any ration in order to provide for the formation or renewal of muscular tissue. Therefore, very broad or very narrow nutritive ratios, corresponding to excessive proportions of carbohydrates or protein, are not desirable in a steady course of feeding. The ratios in the two slops which are under discussion are 1:3.8 for the maize and 1:3.5 for the potato. Both are excessively narrow, and it would be imperative to feed either material in conjunction with other foods rich in fats and carbohydrates.

RATIONS CONTAINING SLOP.

The large proportion of water contained in all slop has an important bearing in determining the amount of slop solids which can be fed to any animal in one day. It has been customary in this country, where cattle have been fed with slop in sheds on the grounds of large whisky and alcohol distilleries and not on the farm, to allow each bullock daily the volume of slop corresponding to a bushel of the grain mashed. In other words, a distillery mashing 1,000 bushels daily will distribute its slop among 1,000 head of cattle. Reduced to volume, this would be equivalent to about 30 gallons per head per day. This amount is excessive, even when fed with considerable quantities of hay and other roughage, as is shown by the flabbiness of the stock and the liquid character of their manure. The injurious effect of the slop when fed excessively, as heretofore in this country, is liable in the case of milch cows to result in dangerous contamination of their milk through the great difficulty of keeping their hind quarters clean.

In Germany, where slop feeding has been practiced very successfully on the basis of careful investigations at the agricultural experiment stations, it is customary to feed much smaller volumes. According to Maercker, it is allowable to give from 18 to 20 gallons per head per day in fattening oxen weighing from 1,300 to 1,400 pounds. More than this amount has been found injurious. Milch cows should not receive more than 16 gallons daily. It is necessary to feed the slop as hot as possible, and since it is especially susceptible to bacterial decomposition it should also be fed when fresh.

Investigations are needed in this country to determine the composition of rations, suited to American conditions, in which potato slop takes its proper place. Pending the institution of such studies, the following German formulas taken from Maercker will serve to show the make-up of balanced rations, for different purposes, which have proved satisfactory abroad.

Rations for young oxen.

Four and five-tenths pounds of digestible protein and 26.5 pounds of starch value per day per 2,200 pounds live weight.

No. 1. Basal ration: 88 pounds of potato slop, 33 pounds of potatoes, 11 pounds of hay, 22 pounds of straw, 6.5 pounds of bran, plus one of the following:

(*a*) 5.5 pounds of cotton-seed meal, 4.4 pounds of rice meal.
(*b*) 5.5 pounds of cotton-seed meal, 4.5 pounds of corn meal.
(*c*) 4.6 pounds of cotton-seed meal, 9 pounds of molasses.

No. 2. Basal ration: 132 pounds of potato slop, 55 pounds of mangel beets, 11 pounds of hay, 22 pounds of straw, 66 pounds of bran, plus one of the following:

(*a*) 3.7 pounds of cotton-seed meal, 9.9 pounds of rice meal.
(*b*) 3.3 pounds of cotton-seed meal, 8.8 pounds of corn meal.
(*c*) 4.4 pounds of cotton-seed meal, 4.4 pounds of molasses, and 4.4 pounds of corn meal or rice meal.

No. 3. Basal ration: 132 pounds of potato slop, 33 pounds of potatoes, 11 pounds of hay, 22 pounds of straw, 6.6 pounds of bran, plus either of the following:

(*a*) 4.4 pounds of cotton-seed meal, 4.4 pounds of rice meal.
(*b*) 3.9 pounds of cotton-seed meal, 4.4 pounds of corn meal.

Rations for fattening grown oxen.

Three and five-tenths pounds of protein and 26.5 pounds of starch value per day per 2,200 pounds live weight.

No. 1. Basal ration: 88 pounds of potato slop, 88 pounds of forage beets, 11 pounds of hay, 26.4 pounds of straw, 6.6 pounds of bran, plus one of the following:

(*a*) 1.1 pounds of cotton-seed meal, 4.4 pounds of rice meal or corn meal, and 6.6 pounds of molasses.

(*b*) 1.6 pounds of cotton-seed meal, 8.8 pounds of rice meal, and 2.2 pounds of molasses.

(*c*) 2.2 pounds of peanut meal, 6.6 pounds of corn meal.

No. 2. Basal ration: 88 pounds of potato slop, 55 pounds of potatoes, 11 pounds of hay, 26.4 pounds of straw, plus either of the following:

(*a*) 4.4 pounds of cotton-seed meal, 4.4 pounds of bran.

(*b*) 4.4 pounds of peanut meal, 4.4 pounds of rice meal.

No. 3. Basal ration: 132 pounds of potato slop, 11 pounds of hay, 26.4 pounds of straw, plus the following: 44 pounds of potatoes, 5.5 pounds of cotton-seed meal, and 3.3 pounds of corn meal.

Rations for dairy cows.

For a daily milk yield of 22 pounds per 1,100 pounds of live weight, there should be fed 3.8 pounds of digestible proteid and 23.1 pounds of starch value per 2,200 pounds of live weight. The following rations fulfill these requirements:

(1) 66 pounds of potato slop, 11 pounds of hay, 26.4 pounds of straw, 44 pounds of mangel beets, 4.4 pounds of cotton-seed meal, 6.6 pounds of palm-nut meal, and 4.4 pounds of bran.

(2) 66 pounds of potato slop, 11 pounds of hay, 26.4 pounds of straw, 4.4 pounds of bran, 4.4 pounds of palm-nut meal, 5.5 pounds of peanut cake, and 6.6 pounds of molasses.

In order that other feeding stuffs may be substituted for those given, the following table has been prepared, showing the composition and average digestibility of the feeds mentioned:

Percentage composition and average digestibility of various feeding stuffs.

[From data compiled by W. A. Henry.[a]]

Feeding stuffs.	Percentage composition.						Per cent of average digestibility.				
	Water.	Ash.	Protein.	Crude fiber.	Nitrogen-free extract.	Ether extract.	Dry matter.	Protein.	Crude fiber.	Nitrogen-free extract.	Ether extract.
Corn meal	15.0	1.4	9.2	1.9	68.7	3.8	88	60	......	93	92
Bran	11.9	5.8	15.4	9.0	53.9	4.0	61	79	22	69	68
Dried brewers' grains	8.2	3.6	19.9	11.0	51.7	5.6	62	79	53	59	91
Rice meal	10.2	8.1	12.0	5.4	51.2	13.1	75	63	26	86	85
Cotton-seed meal	8.2	7.2	42.3	5.6	23.6	13.1	76	88	32	64	93
Palm-nut meal	10.4	4.3	16.8	24.0	35.0	9.5	......	......	......	......	......
Peanut meal	10.7	4.9	47.6	5.1	23.7	8.0	32	71	12	49	90
Hay (mixed grasses)	15.3	5.5	7.4	27.2	42.1	2.5	61	57	60	64	53
Straw (wheat)	9.6	4.2	3.4	38.1	43.4	1.3	43	11	52	38	31
Potato	78.9	1.0	2.1	.6	17.3	.1	85	61	......	90	......
Beet (mangel)	90.9	1.1	1.4	.9	5.5	.2	79	75	43	91	......
Potato slop	93.41	.73	1.97	.55	.34	.04	......	......	......	......	......
Molasses (beet)	20.8	10.6	9.1	......	59.5	......	......	......	......	......	......

[a] Feeds and Feeding, p. 619 et seq. Data credited for the most part to Lindsey, Mass. Agr. Exp. Sta., and certain German authorities.

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